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INFECTED WOUNDS.

Most wounds are contaminated with at least a few bacteria, so that infection should be regarded more as a hazard to be run by all wounds than as an unexplained fate that overtakes some. The most important prophylaxis against wound infection, therefore, is the efficient routine treatment of all fresh wounds. Even when this is carried out, however, contamination leads on to infection in some cases. The number of wounded who develop infection is increased, under the stress of war conditions, by those that have had inadequate treatment. The present article is concerned with wounds which, for one reason or another, have become infected. The most common infections are the pyogenic type, gas gangrene, and tetanus.

Pyogenic Infection.

Source of Infection.

Pyogenic infection is almost always secondary infection; in many cases it can justly be called "hospital" infection. The chief organisms concerned are staphylococci and certain hæmolytic streptococci. Hæmolytic streptococci can be divided into several groups, but those pathogenic for humans are mostly Group A. The pathogenic staphylococci give a positive result to the coagulase test; they are usually hæmolytic, and usually produce a golden pigment when cultured. Other less important pyogenic bacteria are *Bacillus pyocyaneus*, *Bacillus proteus*, and the various coliform organisms. The hæmolytic streptococci are carried by many normal people in the throat, the staphylococci in the nose, and *Bacillus pyocyaneus*, *Bacillus proteus* and the coliforms in the intestine.

In a few cases contamination with these bacteria is more or less inevitable, since they may be present on the skin or the clothes of the patient at the time of wounding. This primary contamination is, however, exceptional. The other sources have been listed as follows: the nose, mouth or skin of those attending the wound; the nose or mouth of the patient; infected wounds of other patients; bed clothing; dust; ward baths; dressings; bed pans; hands and fingers; instruments. These sources are so numerous that many people, from surgeon down to junior nurse, are concerned in protecting the patient from cross-infection. A responsibility that is shared tends to become a responsibility that is shelved, and some English hospitals have therefore appointed one person to the job of teaching and maintaining, throughout the hospital, a proper technique for asepsis. Enough knowledge is now available to show that a problem of cross-infection does exist even under what has usually been considered an adequate system of asepsis. There are also satisfactory means of dealing with this problem, and all surgeons should be familiar with them. They are described in the Medical Research Council War Memorandum Number 6, "The Prevention of Hospital Infection of Wounds", and have been briefly summarized in a previous article.[1]

Débridement of Infected Wounds.

Some patients have localized their infection by the time they first come under treatment, and the wound may not require any surgical interference. In many cases, however, a gentle *débridement* is indicated. The decision as to whether active intervention is required or not is made by considering the following factors: (*a*) quiescence of the wound; if there is no pain, bruising, œdema or tenderness along the wound track, no redness or swelling of the skin margins, and no wound discharge, then the injury is best treated conservatively; (*b*) tenderness and pain; if the wound is tender and painful then the patient should be observed frequently, and if the pain persists during rest, an exploration of the wound should be undertaken; (*c*) disproportionate œdema or increasing œdema; these are signs that infection is developing and requires drainage; (*d*) gas gangrene; if the signs or symptoms of gas gangrene appear, surgical interference is imperative.

The aim of *débridement* is to establish free drainage, to remove blood clot and accessible foreign bodies, and to trim obviously dead tags of tissue. The skin wound is enlarged, the fascia freely divided, and the above objectives accomplished as gently and simply as possible. Most of the work should be done with fingers and scissors. The defensive barrier which the tissues form around the wound must be left intact.

Closed Plaster Treatment.

The closed plaster treatment has been freely accepted as a convenient way of immobilizing fresh wounds after excision. Its application to infected wounds, however, requires further justification, since, as one writer has put it, this seems at first sight to involve the principle of enclosing the wolf in the sheep fold. The justification has been given by the favourable results obtained, and, as often happens, the successful surgical procedure has been supported by various types of theoretical reasoning. It is generally agreed that the plaster ensures rest for the tissues, thus allowing protective thrombi to form, and decreasing toxic absorption through the lymphatics; that it maintains pressure which is beneficial to the circulation of the part; that it prevents meddlesome interference, which is liable to disturb delicate barriers to the spread of infection and, by introducing bacteria, to add sepsis to sepsis; and that it permits pus to seep away from the wound. A plaster should never be applied if the surgeon is doubtful of the circulation of the part or if the patient is likely to be evacuated and come under the care of a different surgeon. In cases of severe cellulitis, too, many surgeons prefer to immobilize the part affected by means of an open splint, and watch progress; in fact, the commonest English practice is to withhold plaster until acute infection of any kind has subsided.

The wound is first lightly packed with "Vaseline" gauze. It has been pointed out that the word "pack" is rather unfortunately chosen, since it suggests tight plugging, which is strongly contraindicated. The plaster is applied directly to the skin, except that prominent bony points are protected by padding. This direct application is advised, partly to prevent movement within the plaster, and partly because it is thought that a uniform pressure from the cast is beneficial in preventing œdema, and so in maintaining the circulation of the subcutaneous tissues.

The joint immediately above the wound and that immediately below must be immobilized, and the limb must be maintained in the position of function. If the wound is on the wrist or forearm, the plaster must extend above the elbow; if the elbow or shoulder is involved, a shoulder spica is used, and this is carried down to embrace the iliac crests. In applying a shoulder spica, the arm is abducted 45° and carried forward 45° from the coronal

plane; the forearm is set at right angles to the arm, and midway between pronation and supination; the wrist is slightly extended, the thumb abducted, and the part of the hand beyond the distal palmar crease is left free. In wounds of the ankle, the plaster includes the whole foot except the dorsum of the toes and is carried up to the knee; in wounds of the leg and the knee it is continued to the groin and the hip respectively. Hamilton Bailey does not use this method for wounds on the upper half of the thigh, because he considers that such wounds are so liable to complications that they are better left uncovered by plaster. If it is desired to immobilize the thigh, a double hip spica must be used and the sound leg must be included as far down as the knee.

The first plaster seldom requires removal in less than a month. An unpleasant smell always develops, but this may be overcome by enclosing the limb in a deodorizing bag. The bag fits loosely over the plaster and is secured at the proximal end with a draw tape. It is made of material in which, by a secret process, powdered charcoal has been incorporated. The cloth does not deteriorate when stored, but the charcoal becomes exhausted after about two to five weeks' use. It loses its effectiveness when wet, but recovers on subsequent drying.

The application of the plaster usually causes a rise in temperature, but this may be ignored unless it lasts more than three or four days. The indications for removal of the plaster are: (*a*) pyrexia accompanied by listlessness, or increased pulse rate, or marked local pain, or œdema of the distal portion of the extremity; (*b*) undue loosening of the plaster; (*c*) secondary hæmorrhage; (*d*) constriction of the circulation by a cast applied too tightly. A new plaster may be applied after the cause of the trouble has been dealt with. The wound discharge sometimes causes a dermatitis, but this responds well if a few days' interval is left before the next plaster is applied. When the closed plaster method is used successfully, the patient remains in good general condition and is very comfortable.

The closed plaster method has practically replaced the methods which were used in the last war for the treatment of wound infection, and which were carried on into the more limited practice of peace time. Continuous irrigations, the use of "bipp", and the use of strong salt solutions were undoubtedly helpful in some cases, but the modern tendency is to place great emphasis on the value of immobilization, and this is admirably provided by plaster casts. The principle of immobilization is, of course, merely a rediscovery, since Hilton and Thomas also insisted that inflamed tissues needed rest. Recent work has given a rationale for this treatment, however, by showing how it limits the flow of lymph from the affected part, and so decreases the most important channels by which bacteria and their toxins are disseminated. The immobilization involves disuse of muscles, but this is more than compensated for by the localization of the infection and the resulting reduction of fibrosis.

One of the complications of complete rest is seen in those cases in which, on account of the presence of a fracture, the injured part has to be maintained at an angle to the horizontal. Infected fluid tends to seep into the dependent part and cause a gravitational abscess. These new infections develop insidiously. They must be carefully watched for, and incised as soon as they appear.

Chemotherapy.

The use of either Dakin's solution or eusol for infected wounds has not been superseded entirely, but it has been strongly criticized. Even when the irrigation is carefully sprayed throughout the wound by Carrel tubes at two-hourly intervals, the antiseptic is active for only short periods of about ten minutes at a time. It is irritating if not used fresh and is damaging to granulation tissue. Probably the effect in dissolving necrotic tissue and promoting an outpouring of plasma is more important than the bactericidal action. The Carrel-Dakin method may be used in the early treatment of badly infected wounds, if it is considered too risky to apply a plaster at once. In other cases, if plaster immobilization is not thought necessary, irrigations may be continued for about ten days and be followed by secondary suture. Dakin's solution or eusol is also used to prepare a surface for skin grafting; if the infecting organism is a hæmolytic streptococcus, however, such a preparation is inferior to that obtained by using saline baths and sulphanilamide powder.

A recent modification of this treatment is the use of sodium hypochlorite solutions in Bunyan-Stannard envelopes. The hypochlorite solution is prepared from sodium chloride by electrolysis, and excess chloride remains in the solution. The method is especially useful for infected hands or fingers, since it prevents cross-infection and permits an early return of function.

Probably the most effective use of irrigation, however, is to employ the saline bath in conjunction with sulphonamide dressings. Here the saline solution is used merely for its mechanical cleansing action, and the sulphonamide powder acts on the organisms in the intervals between the baths.

Interest in chemotherapy has been stimulated by the introduction of the sulphonamide compounds. It is not yet clear what rôle these compounds will play in the local treatment of obviously infected wounds. The tendency has been to discount them, since it is well known that pus contains large amounts of anti-sulphonamide substances and that the sulphonamides do not diffuse readily into necrotic tissue. These objections can possibly be countered if the pus is irrigated away before the sulphonamide is applied and if the necrotic tissue is minimal. Sulphonamides have a very important field of application in preparing for skin grafts surfaces that are infected with streptococci; their effectiveness in this case is undoubted. In addition, all are agreed that a man with infected wounds should be given sulphonamide by mouth.

An antiseptic which has recently been used with success in some cases of intractable infection is proflavine sulphate (2:8 diaminoacridine sulphate). The acridine dyes are well-known antiseptics, but in the past acriflavine was usually the one selected, perhaps because it was the most soluble and therefore the easiest to dispense. Acriflavine is not a definite chemical compound, but a mixture of related compounds, so that its composition is variable, and its action uncertain; because of its affinity for gauze most of the acriflavine from a 1 in 1,000 solution is absorbed by the dressing. Proflavine is just as effective against bacteria as good acriflavine and is less toxic. In the cases under discussion[3] it was used as a powder, in amounts of from one-quarter of a gramme to two grammes—quantities which are non-toxic. Proflavine is active against most of the common pyogenic organisms except *Bacillus proteus*.

A homely chemical agent which is useful for destroying *Bacillus pyocyaneus* is acetic acid, used in a 1% concentration. *Bacillus pyocyaneus* has been described as being merely a nuisance, but it has to be removed from granulating surfaces before skin grafts will take.

One of the important problems in the use of sulphonamides is that certain organisms can become resistant to the drug, if they are treated unsuccessfully for some time. Even an expensive remedy is worth while if it can cure wounds infected with these drug-resistant strains, because it is obviously undesirable to have such bacteria spread throughout the community. A partial answer to this problem has been supplied by the use of the so-called "biological antiseptics", of which the two most important are penicillin and tyrothricin.

Penicillin is a product from the mould *Penicillium notatum*. It is much more active against the staphylococcus and certain other Gram-positive organisms than are the sulphonamides. It would therefore be widely used if it were not so expensive to produce. The yield from about one hundred litres of culture is sufficient to treat only one patient intravenously for one day. The prospects of synthesis of the compound are not yet good, since the molecule is so complex and unstable that its structure is not known. Penicillin is much less toxic than the sulphonamides and is not adversely affected by tissue constituents.

Tyrothricin is a crude extract obtained from a soil bacillus. It can be divided into two active constituents; gramicidin, which makes up 15% of the whole, and tyrocidin. Gramicidin is the more powerful and less toxic of these two components, but its action is almost confined

to Gram-positive organisms. Tyrocidin acts on some Gram-negative as well as some Gram-positive bacteria.

Tyrocidin is more toxic than penicillin, but easier to produce. It is too toxic for any method of use other than local application. Gramicidin seems to be the more favoured preparation. It is poorly soluble in water, but dissolves in alcohol and glycerin. It has been used successfully against streptococcal infections, but is less effective against staphylococci.

Healing of Infected Wounds.

When the wound surface has granulated over and become relatively sterile, it can, in some cases, be closed by secondary suture; it is useless, of course, to suture an infected wound. If the loss of epithelium is too great for secondary suture, skin grafting should be done. The longer skin grafting is delayed, the more fibrosis occurs. This fibrosis favours the continuance of infection, and makes the bed of granulations less suitable for the support of the graft. Therefore, when skin grafting is necessary it should be done as soon as possible; early grafting has the further advantage of hastening a return of function.

It has long been recognized that many general factors condition the rate of wound healing, and therefore the patient must not be forgotten while you are attempting to kill his bacteria. The rather vague idea that the wounded man needs an "adequate" diet has been defined to the extent of prescribing more than the average allowance of protein and vitamin *C*, and less than the average intake of carbohydrate. Lowered protein reserves may be restored quickly by blood transfusion.

Reports on the various preparations so far suggested as local stimulants to healing have become less and less enthusiastic.

Very chronic wounds may result from retained foreign bodies, especially from the larger ones. Removal of the foreign body is therefore desirable, but it involves the danger of opening up new paths of infection. This danger is lessened if careful localization of the foreign body is made prior to operation. Sometimes when the landmarks are favourable it may be necessary merely to take two skiagrams in planes at right angles to each other, but at other times the use of an X-ray localizer may be required. Apart from the ability to localize the foreign body accurately, there are other factors which help to determine whether operation is indicated: (*a*) the condition of the patient; (*b*) the size and number of the foreign bodies; (*c*) the accessibility of the foreign bodies.

A plan must be made regarding the approach to the foreign body so that removal may be carried out with the least possible disturbance of important anatomical structures. In general, there are two possibilities:[6] the original track may be followed, or an approach may be made through healthy tissue.

In the first case, the wound of entrance is enlarged, necrotic tissue is excised, and exploration is carried out by probe or scoop. A counter-incision may be necessary to facilitate removal of the foreign body or to establish drainage. Fluoroscopic control does not give the skilful surgeon any information that he cannot readily obtain by other means.

The second method of approach is especially useful when the foreign body has penetrated so deeply that it can be approached most easily from a new direction. One then selects the shortest possible route through anatomical planes to the foreign body. It is important to remove secondary foreign bodies such as fragments of clothing.

Owing to the non-standardized nature of these operations, the skill of the surgeon may be severely taxed. Even when the operation has been successfully carried out, certain complications may occur: (*a*) secondary hæmorrhage, especially if the foreign body has been close to a blood vessel; (*b*) the stirring-up of latent aerobic infection; and (*c*) the development of anaerobic infection.

Skin Grafting.

Details are available of a technique of skin grafting which was used successfully in the Middle East at an Australian general hospital.[6] The feature of the method is the successful use of sulphanilamide powder to prepare granulating surfaces for secondary grafting.

Skin grafting is essential whenever more than about three square inches of skin have been completely destroyed, although size is considered in relation to the shape and position of the wound. If grafting is not undertaken one has to wait for skin to grow in from the epithelial edge. Streptococcal infection of the granulations is very common and much fibrosis is produced as a result. The advancing skin therefore moves on to a bed of tissue which becomes less and less suitable as a support. The process of healing under these conditions is slow and unsatisfactory. It is well recognized, for example, that skin formed under the closed plaster treatment is poor in quality. This and other forms of early treatment should be supplemented in cases of extensive skin loss by skin grafting.

The preparation for skin grafting involves the use of saline baths and sulphanilamide dressings. Attention is also paid to certain local and general conditions which may prejudice the result of the graft: the infecting organisms are identified, an examination is carried out for retained foreign bodies, blood transfusion is given if the hæmoglobin value is low, and extra efforts are made to improve the diet.

Saline baths are given under the care of an orderly once a day, each bath lasting for as long as the patient can bear. An ordinary bath tub may be used or, when an extremity only is wounded, an arm bath or a foot bath may be adequate.

The fluid used in the bath is hypertonic saline solution (2%). This is made up from a 20% stock solution kept in a tank and added through a filter when required. The temperature of the fluid is uncomfortable if it rises above 90° F. On the other hand, the solution must not be allowed to cool off unduly; the temperature is taken from time to time, and in the case of the longer baths, it may be necessary to add fresh hot solution. Bath-tubs are fitted with trays which enable the patient to read, smoke, or take his meals. The first bath lasts only about half an hour and is half-strength, but the time may be rapidly increased to three or four hours in most cases. During the bath the previous day's dressing is soaked off and the attendant uses forceps to remove as much slough and débris as possible.

The bathing brings about mechanical cleaning of the wound and permits function to be maintained. This treatment has the disadvantages of involving a great deal of work for the attendants and of creating opportunities for cross-infection. To overcome the latter the tubs must be carefully sterilized by ten minutes' washing with a 5% solution of "Lysol" following each bath.

After the bath, the wounds are dressed by the technique designed to prevent "hospital" infection. If the contaminating organism is the hæmolytic streptococcus, necrotic tissue is cut away, and sulphanilamide powder is applied. The surface receiving the powder must be moist. The wound is then covered with *tulle gras*, and moist saline solution packs are applied and bandaged on. The dressing is kept moist all day by being rewet two or three times. The moist *tulle gras* dressing comes off very easily in the next bath.

In the evening crêpe bandages are firmly applied. The object of this is to use pressure in order to obtain a regular, firm granulating surface.

If the organisms present are not streptococci, the sulphanilamide is omitted and the saline packs are replaced by eusol for two out of every three days.

These methods of preparation usually produce a suitable surface for grafting in about seven days. Grafting is proceeded with until the clinical appearance and bacteriological examination are both satisfactory. The two main types of graft are pinch grafts and razor grafts. In pinch grafting, small cones of skin are removed under local anæsthesia and applied to the granulations. The usefulness of the method is limited, because the granulations are not covered completely, so that final healing is slow and the functional result is poor. Razor grafts give uniformly good results, but sufficient donor skin must be available, and a general anæsthetic has to be administered.

Passive and Active Immunization.

Passive immunization against tetanus was used with outstanding success in the war of 1914-1918. It has, nevertheless, certain unsatisfactory features: the protection lasts for about ten days only; the serum is rather expensive; serum reactions occur in some cases; and finally, since tetanus can develop from a very insignificant wound, the antiserum has to be given to all the wounded as a routine, and this is troublesome. Nevertheless, in the present state of our knowledge, passive immunization is still considered necessary, even for those who have received injections for active immunization. Every wounded person, however trivial the wound, should be given, by intramuscular or deep subcutaneous injection, an initial dose of three cubic centimetres of antitetanus serum, which is equivalent to not less than 3,000 international units. No reduction in the dose should be made in the case of children, since the amount of toxin produced by the organisms does not depend on the size of the patient. An important step, the omission of which has been responsible for some recent cases of tetanus, is that two further doses of three cubic centimetres each should be given at weekly intervals to all patients who have not been immunized with tetanus toxoid.

The introduction of a method of active immunization has been an important advance. An alum-precipitated toxoid gives the best results. The initial dose is one cubic centimetre, administered subcutaneously; after a further one to three months this dose is repeated. The immunity produced by these two doses is fairly satisfactory, but a third injection is given after a similar interval to ensure a definite response. It is not easy to determine how long this immunity lasts, for the measurement of the amount of anti-tetanus antibody in the blood stream is time-consuming and expensive, and insufficient data have so far been collected. In the meanwhile it seems advisable to give a fourth injection at the time of any possible infection. It is worth noting that if tetanus toxoid is given with typhoid paratyphoid vaccine, the response to the toxoid is five times greater than when toxoid is given alone.[1]

Sufficient evidence has already been obtained to prove that tetanus toxoid is an effective prophylactic. In the British Expeditionary Force which fought in Flanders during the present war, 90% of the men were immunized against tetanus. Each wounded man was also to receive 3,000 units of antitoxin, but this was not always possible. There were eight cases of tetanus among 1,800 non-immunized wounded, but there were no cases among 16,000 wounded who had been actively immunized. Again, practically all the soldiers of the French fighting forces were immunized, and only one mild case of tetanus occurred amongst them. A further example is that there were no Americans who developed tetanus after the enemy raid on Pearl Harbour. This is all the more remarkable in that every month, for the past seven years, an average of two people in the territory of Hawaii contracted tetanus.

All the early reports on active immunization against tetanus agreed that very few patients had an unfavourable reaction to the injections. A few patients developed anaphylaxis and a few more had constitutional symptoms such as malaise and fever. During 1941, however, an outbreak of severe reactions appeared, the incidence in some places being as high as 25%.[2] An intensive study revealed that these results were due to the use of certain peptones in the media in which the *Clostridium tetani* was grown. When other peptones were used the toxic effects did not appear.

Mode of Action of Tetanus Toxin.

Recent investigations of the mode of action of tetanus toxin[3] have modified previous views. The toxin produced in the wound diffuses through the adjacent muscle and acts on the neuro-muscular end-organs to cause increased muscle tone. Some of the toxin is absorbed into the general circulation through the blood vessels and lymphatics. This toxin affects other neuro-muscular end-organs, but it is also taken up by the central nervous system. In the central nervous system the toxin probably forms a secondary substance which is not neutralized by anti-tetanus serum. The secondary substance causes death by paralysing the respiratory centre.

Treatment of Tetanus.

There are two controversial points about the giving of antiserum, namely, whether it should be given intrathecally or not, and whether it should be given repeatedly or not.

Intrathecal injection of the antiserum was introduced when it was believed that the toxin was absorbed by the axis cylinders of motor nerves. It is now generally accepted that the toxin is absorbed into the blood vessels and lymphatics, so that the antiserum reaches the toxin more directly when given intravenously, or even intramuscularly. Some authors, also, have pointed out difficulties and dangers of intrathecal injection: it increases the liability to reflex spasms; it tends to cause a serous meningitis; and it may induce a severe reaction. There are, therefore, good reasons for giving the serum intravenously, and this is the method at present recommended, but the case is not finally decided; some of the recent as well as the older work points to the intrathecal route as being more effective therapeutically.

Whether injections of antiserum have to be repeated depends on whether the antitoxin disappears quickly from the blood stream. The evidence on this point is not complete because, as mentioned previously, the estimation of antitoxin titre is not easy. However, the results suggest that weekly doses are quite adequate.

The serum should be given as early as possible. The Ministry of Health in England recommends that 200,000 international units of antiserum should be given intravenously as an initial dose in all severe cases. A further 50,000 units should be given every seven days until the reflex spasms begin to subside.

When this serum is given, inquiry should first be made as to previous serum therapy and history of allergy. Desensitization is carried out if there is a suspicion that the patient is hypersensitive to serum. In any case the serum should be given slowly, and adrenaline should be at hand in case of emergency.

One hour after the antiserum has been given, the wound should be treated. The aim is to convert it into an aerobic wound by thorough drainage, evacuation of pus, and removal of foreign bodies and necrotic tissue. The wound is subsequently irrigated every four hours with hydrogen peroxide.

The patient is kept in a quiet, darkened room. The sedatives preferred are bromide, if the symptoms are not severe, and "Avertin" or paraldehyde in the more advanced cases. The dose of "Avertin" *per rectum* is up to 0·1 cubic centimetre of fluid "Avertin" per kilogram of body weight, and of paraldehyde, one-half to one drachm per stone of body weight. Two or more doses per day may be needed. Injections of "Evipan" may be needed for sudden, severe spasms.

An attempt should be made to give 1,000 Calories of food per day in a fluid form. At least three pints of liquid are necessary to maintain fluid balance. All handling of the patient should be done with as little disturbance as possible.

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